Forecasts of the Size of the Area 10 Sockeye Salmon *(Oncorhynchus nerka)* Stock from 1985-1990

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ABSTRACT

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Four models are developed to generate pre-season forecasts of the size of the Area 10 adult sockeye salmon stock for the years 1985-1990. Three of the models involve linear regressions of total actual returns (catch plus escapement) on total expected returns beginning with the 1972 brood year. The expected return for any given year is determined from brood year escapements and historical information on return rate per spawner and the average age structure of returns. The fourth model assumes the actual return is limited to 550000 whenever expected return is $\geq$ 550000. The reliability of the forecasts for 1985 and 1986 are evaluated and forecasts fpr 1987-1990 are provided.

RÉSUMÉ

Henderson, M. A. 1987. Forecasts of the size of the Area 10 adult sockeye salmon (Oncorhynchus nerka) stock from 1985-1990. Can. MS Rep. Fish. Aquat. Sci. 1916: 21 p.

On a élaboré quatre modèles pour trèvoir, avant la saison, la taille du stock de saumon rouge adulte du secteur 10 pour les années de 1985 à 1990. Trois des modèles comportent des régressions linéaires du total des retours réels (prises plus la remonte) sur le total des retours prévus à partir de l'année de génération de 1972. Le retour prévu pour une année donnée est déterminé à partir des remontes de l'année de génération et des données sur le taux de retour par géniteur et la structure d'âge moyen des retours. Le quatrième modèle présume que le retour réel est limité à 550 000 chaque fois que le retour prévu est $\geq$ à 550 000. On évalue la fiabilité des prévisions pour 1985 et 1986 et on présente les prévisions pour la période de 1987 à 1990.

INTRODUCTION

Sockeye salmon constitute an important part of the total British Columbia salmon catch. Although the total annual sockeye catch in British Columbia is dominated by returns to the three largest sockeye producing systems in the Province, the Nass, Skeena and Fraser rivers (Starr et al. 1984), numerous smaller sockeye stocks do make important contributions to regional fisheries. Included in this list is the Area 10 sockeye stock.

The Area 10 sockeye stock originates from two spawning areas within the Canadian Department of Fisheries and Oceans Statistical Area 10 (Henderson et al. 1986). This area is located on the central coast of British Columbia slightly north of Vancouver Island between 51° 10' and 51° 20' north latitude (Fig. 1). The stock is fished in Smith Sound and Smith Inlet using gillnets and is not known to be intercepted in fisheries outside Statistical Area 10.

An annual forecast of the total run size of returning Area 10 sockeye is an important piece of information useful for managing the stock. In particular, a reliable forecast would enable the manager to conduct an orderly harvest of any surplus return while achieving the escapement target of 200,000 with appropriate contributions from all segments of the run. Henderson et al. (1986) reviewed the reliability of several different types of models, both pre-season and in-season, used to forecast the total run size of Area 10 adult sockeye salmon. The results of the study showed that a simple pre-season forecast known as the return rate model which is based on brood year escapement, age structure of returns and number of returns per spawner provided the best forecast of total Area 10 sockeye salmon returns.

The purpose of this study is to generate forecasts of the total Area 10 adult sockeye salmon return for the years from 1985 to 1990 using the return rate model.

METHODS

The return rate model is developed by regressing the actual return (catch plus escapement) of sockeye salmon to Statistical Area 10 in year i on the expected return for year i. The expected return for year i is calculated by first determining the average portion of four and five year old sockeye salmon in the returning stock over a base period from 1972-1986 based on age samples collected from the fisher, at the Docee fence and on the spawning grounds (Fig. 1). Next, the total expected return from escapements in years i-4 and i-5 is estimated by taking the product of the escapement and return rate per spawner. Long Lake (Fig. 1), the nursery lake for Area 10 sockeye salmon, was fertilized in 1976, 1977, 1978 and each year since 1981. The

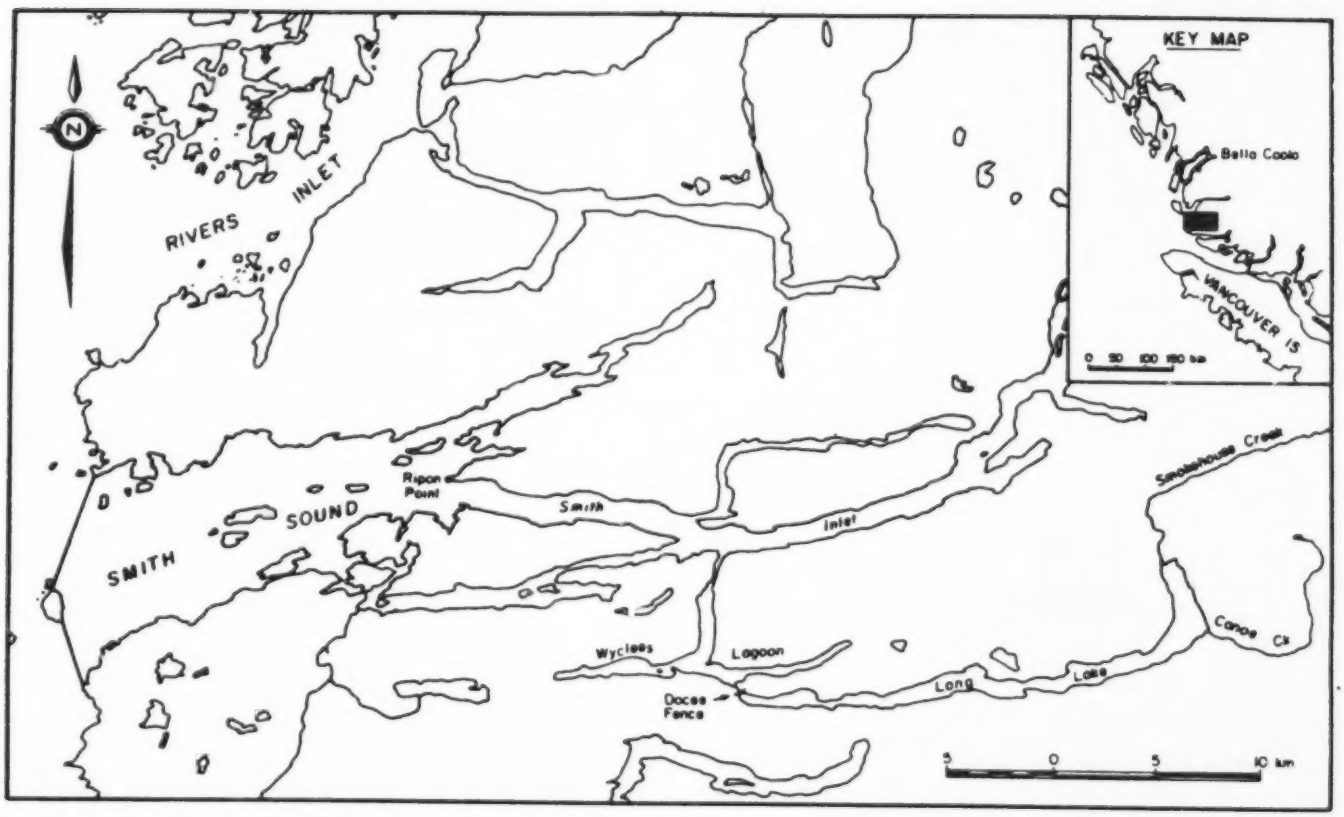

Fig.1 Area 10 and vicinity. Shaded area shows the location of the Area 10 sockeye salmon fishery.

return rate for the 1975, 1976, and 1977 brood years, and each brood year since 1980 is estimated to be 4.0:1.0. For all other years, the return rate is estimated to be 2.5:1.0. The total expected returns from brood years i-4 and i-5 is then apportioned according to the average age structure of returns which is approximately 35% four year olds and 65% five year olds. Finally, expected returns from both brood years are summed to produce the expected run size for year i.

The return rate model is of the form:

$$Y_i = B_o X_{io} + B_i X_{i1} + E_i$$

where

Y_i = forecast stock size for year i

X_{io} = 1

X_{i1} = the expected stock size in year i

B_o = the intercept

B_i = the partial regression coefficient for the X_i

E_i = the random component

Forecast run sizes for 1985, 1986, and 1987 through 1990 are based on actual and expected return data for years 1972-1984, 1972-1985, and 1972-1986 respectively. Each data series begins in 1972 to correspond with the time when the Docee fence, through which all Area 10 sockeye that escape the fishery must pass, become operational. Further details on the compilation and interpretation of the catch and escapement data, the near-shore migratory behavior of Area 10 adult sockeye salmon and dynamics of the fishery are provided in Henderson et al. (1986).

RESULTS

The total run size of the Area 10 adult sockeye salmon stock has shown considerable variation since 1972 ranging from a low of 31650 in 1979 to over 500000 in 1985 and 1986 (Fig. 2). Over this period there is some evidence of a four year cycle with the largest run sizes occurring in 1973 and 1974, 1977 and 1978, 1981 and 1982, and 1985 and 1986. Similar variation is evident in escapement estimates with a low of approximately 20000 in 1979 to 250000 in 1985. Beginning in 1980 there was an attempt to get more fish through to the spawning grounds in anticipation of greater returns in the future. As a result, average escapement has more than doubled from 87000 for the period 1972-1979 to 185000 for the period 1980 to 1986.

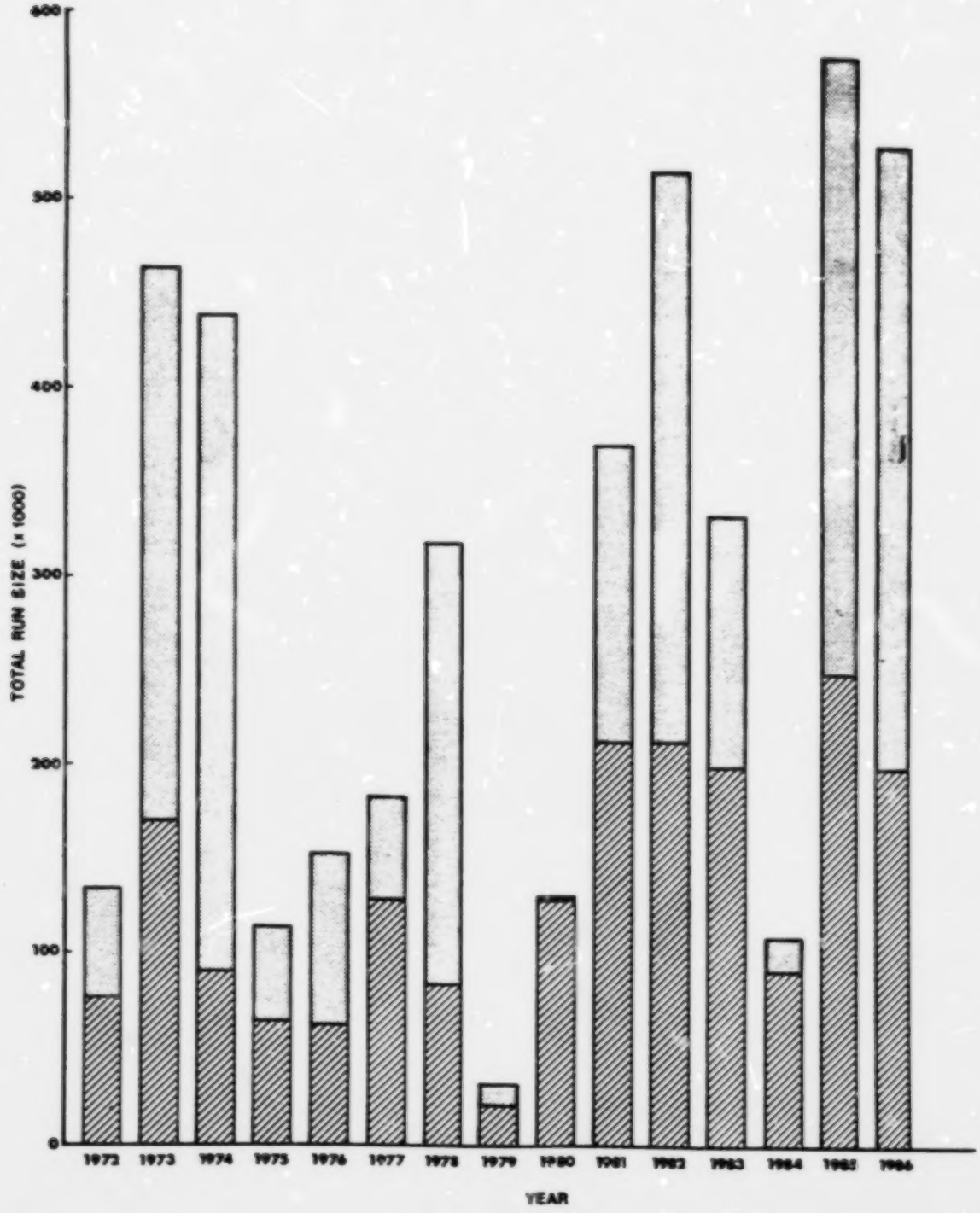

Fig.2 Catch (stipled), escapement (cross-hatched) and total run size of Area 10 sockeye salmon, 1972-1986.

Adult sockeye returning to Area 10 consist almost exclusively of fish aged 4_2 and 5_2. A very small number (<0.5%) return at age 6_3. No jacks (3_2) have been found in the Area 10 sockeye stock. In nine years since 1972 the adult return has been dominated by fish aged 5_2 (Fig. 3). Fish aged 4_2 were more abundant than those aged 5_2 in 1972, 1981 and 1985. No age structure information is available for 1976, 1979 and 1984.

The rate of return per spawner for Area 10 adult sockeye has varied from 2.1 for the 1976 brood year to 5.3 for the 1977 brood year (Fig. 4). Although the rate of return per spawner of fish aged 5_2 generally exceeded that of fish aged 4_2, the ratio of 5_2:4_2 was not stable. Of particular interest with regard to the 1986 forecast for the total sockeye salmon return to Area 10 (see below) was the difference in the rate of return per spawner of fish aged 4_2 from the 1981 and 1982 brood years. Although both brood years had an almost identical escapement (Fig. 2) the rate of return from the 1981 brood year was almost three times greater than from the 1982 brood year.

Three regressions of actual returns on expected returns were developed in this study (Fig. 5) The first regresion, denoted as Model I, required the 1977-1984 time series and was used to forecast the 1985 Area 10 adult sockeye salmon run size. The 1977-1985 time series was used in formulating Model II and generating forecasts of run size for the period 1986-1990. Model III utilized data from 1977-1986 and provided forecasts for years 1987-1990. The intercepts and partial regression coefficients for the three models are:

	B_0	B_1
Model I	-182231	+1.53
Model II	-134965	+1.34
Model III	+38544	+0.74

The total run size in 1985, 575683 (Fig.2), was adequately forecast by Model I which produced a midpoint forecast of 671875 and a 95% confidence interval range of 456943 - 886807 (Table 1). Model II which incorporated the actual and expected returns for 1985 into the 1977-1984 time series generated a run size forecast for Area 10 sockeye salmon in 1986 of approximately 1000000 $\pm$ 270000. The 1986 forecast, however, was in error with the lower end of the 95% confidence interval exceeding the total run size for 1986 by 220000. Forecasts of total run size using Model II for 1987 through 1990 range from approximately 665000 in 1989 to over 1000000 in 1987 and 1990. Model III, developed from the 1977-1986 time series was used to provide forecasts for 1987-1990 (Table 1). These forecasts were substantially lower than those from Model II as a result of the 1986 data on actual and expected returns which served to decrease the slope of the regression from 1.34 to 0.74. Model IV was developed on the assumption that the Area 10 sockeye production system is limited to producing no more than approximately 550000 adult sockeye salmon annually. Consequently, in each year when the expected return is in excess of 550000 (when calculated as described above) the forecast return is 550000. In years when the expected return is <550000 the

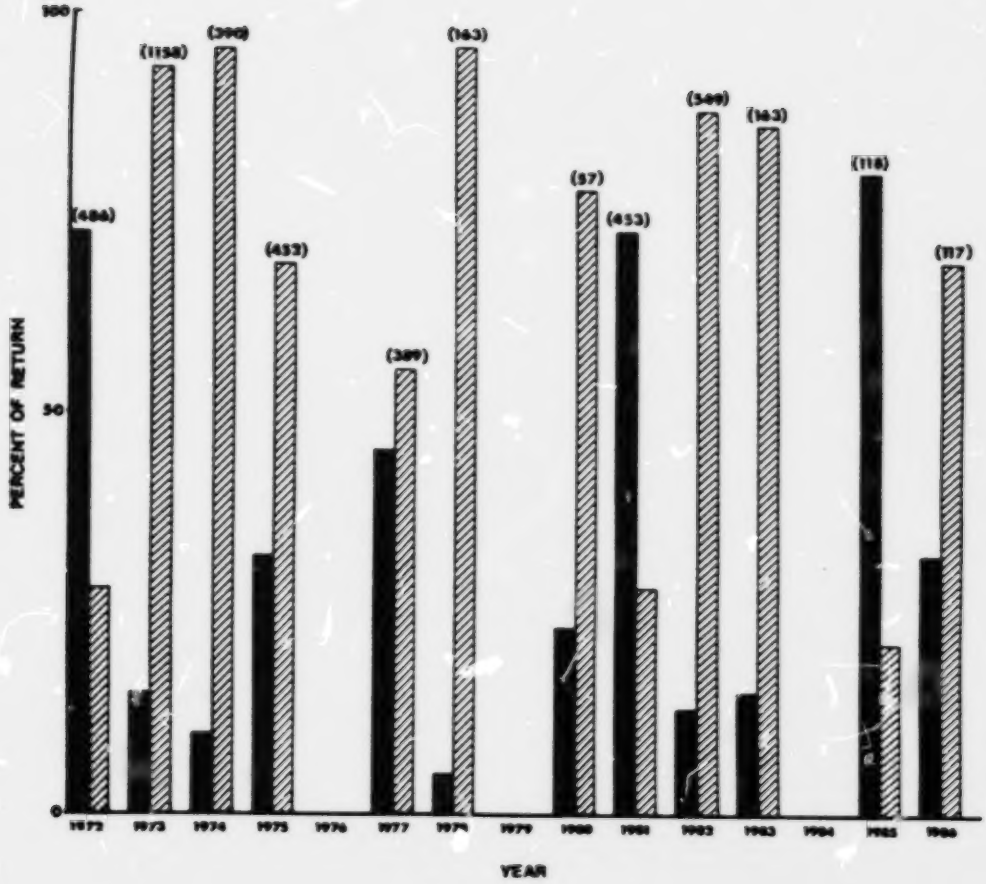

Fig.3 Age structure of Area 10 adult sockeye salmon, 1972-1986. Age 4_2 and 5_2 sockeye are shown by solid and cross-hatched bars respectively. The number of fish aged each year is shown in parenthesis. No age data is available for 1976, 1979 and 1984.

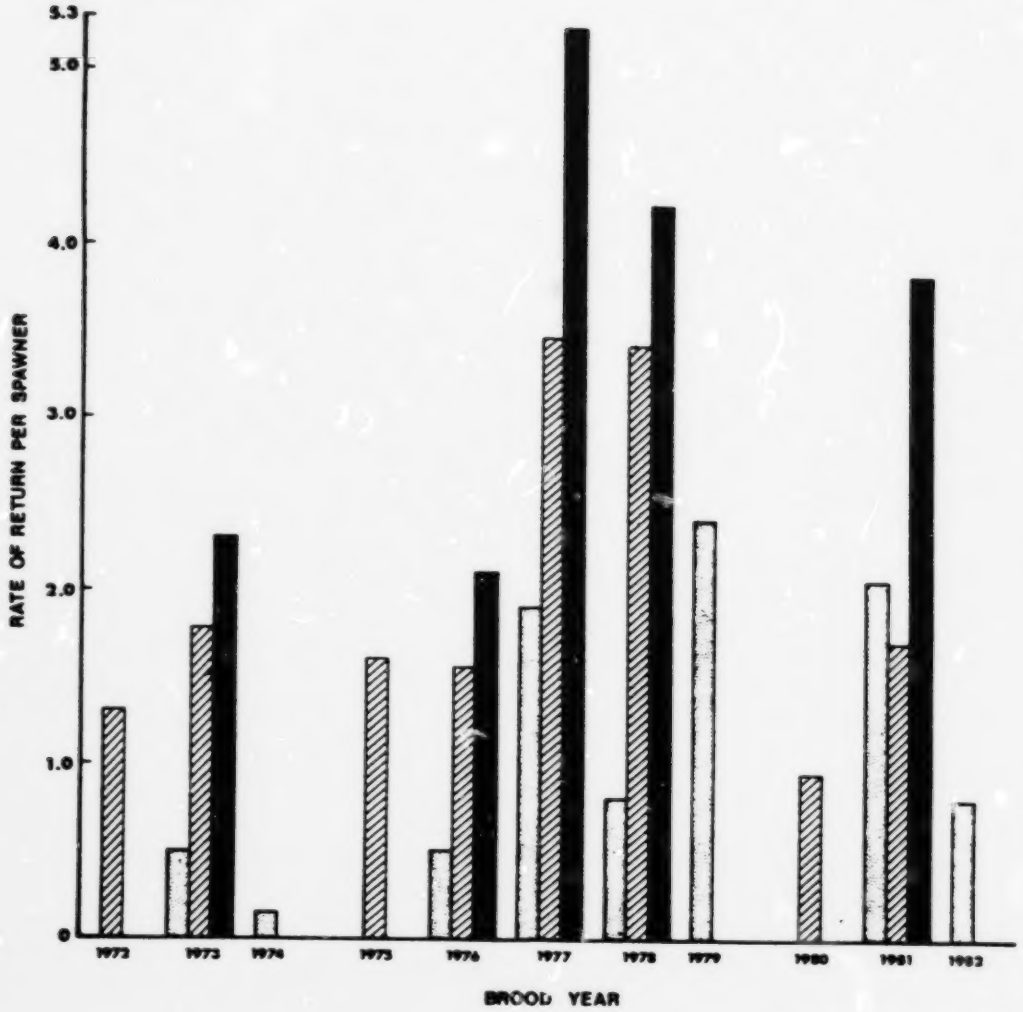

Fig.4 Number of sockeye salmon returning per spawner for brood years from 1972-1982. The return rate of 4_2 and 5_2 sockeye is shown by the stipled and cross-hatched bars respectively. The solid bars show the total return rate per spawner.

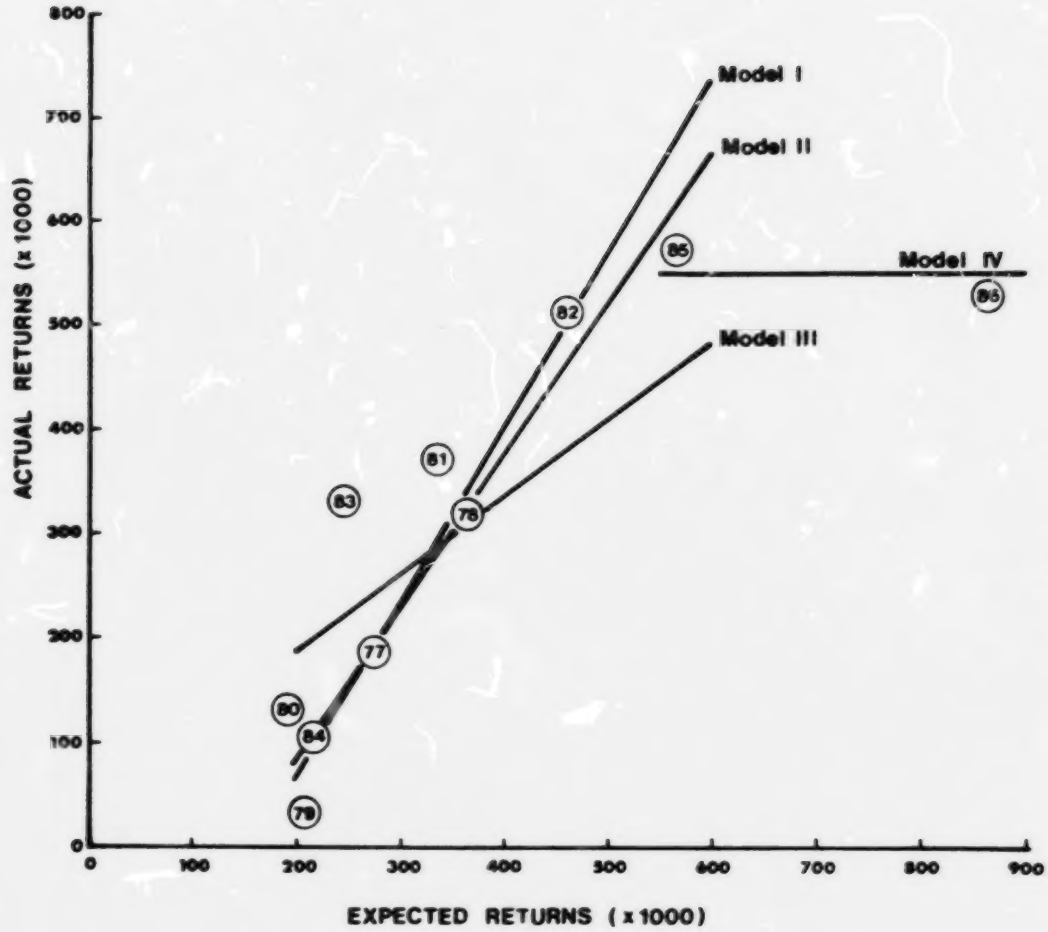

Fig.5 Regression lines for actual returns as a function of expected returns for Models I-IV. See text for details. The number in each circle indicates a particular year.

Table 1. Forecasts of the total annual sockeye return to Statistical Area 10 from 1985 to 1990. Models I, II and III correspond to regressions of actual returns as a function of expected returns for the years 1977-1984, 1977-1985 and 1977-1986 respectively. Model IV limits returns to 550000 in all years where the expectation is $\geq$ 550000. 95% confidence intervals shown in parenthesis.

	1985	1986	1987
Model I	671875 (± 214932)		
Model II		1018016 (± 269236)	1002156 (± 263698)
Model III			661166 (± 212784)
Model IV			550000 (N/A)

	1988	1989	1990
Model II	736681 (± 171922)	662782 (± 147276)	1117525 (± 304148)
Model III	517340 (± 141411)	476748 (± 123687)	726383 (± 245319)
Model IV	550000 (N/A)	550000 (N/A)	550000 (N/A)

forecast return would be determined by a return rate regression model as described above. The forecast return of Area 10 sockeye salmon using model IV is 550000 for 1987-1990. As model IV is qualitative in nature no error structure is associated with these forecasts.

DISCUSSION

The analysis presented in this report raises two very important questions with regard to forecasts of total returns of Area 10 adult sockeye salmon. First, why was there such a large difference between the forecast return for 1986 (1018016 ± 269236) (Table I) and the actual return (528641) (Fig. 2)? Second, what model provides the most reliable forecasts for 1987-1990? Although there is no definitive answer to either question at this time, possible answers for the former and the most reasonable choice for the latter can be provided using other sources of information.

The total run size forecast for 1986 (Table 1) was developed by regressing only 9 years of actual returns on expected returns. Consequently, this very short time series (1977-1985) may not adequately reflect the real level of variation between expected and actual returns for the Area 10 sockeye production system when expected returns are derived as described above. Also, the forecast run size derived for 1986 was approximately 60% greater than the largest forecast return used in constructing the regression. Such forecasts of future returns that lie outside the historical time series of data used to construct the regression are suspect. In such situations it must be assumed that the model providing the best fit to the historical time series of data (a linear regression model in our example) is also appropriate for representing data whose values lie outside that time series. In the case of Area 10 sockeye it was assumed implicitly that the large escapements in 1981 and 1982 (Fig. 2) would produce large numbers of smolts and finally adult returns in 1986. Although the cause for the lower than expected return in 1986 is not clear there are examples in other sockeye systems where the relationship between smolts produced and returning adults is either not obvious or when it is obvious is non-linear (Peterman 1978, 1982). The relationship between actual and expected returns for the period 1977 - 1985 (Fig. 5) does appear well defined for Area 10 sockeye. Consequently, it appears that the relationship between actual and expected returns in 1986 indicates either that the linear model does not hold when expectations are in excess of approximately 550000 and that returns of this magnitude are the maximum we can expect from the Area 10 sockeye production system or that some event, in either the freshwater or marine environment not present in other years of this study, had a negative impact on the rate of return per spawner for the 1981 and/or 1982 brood years.

Although it is not known if any particular event reduced survival of the 1981 and/or 1982 brood years to less than that experienced in previous brood years since 1972, it is of interest to note that the return of sockeye

salmon to most North American systems, excluding Bristol Bay and Fraser River, was dramatically lower than expected. These systems with lower than expected returns are widely spaced along the coast and include southern Southeast Alaska, the Nass and Skeena rivers, Barkley Sound and Rivers Inlet, a system immediately adjacent to Area 10. The above suggests some large scale event may have reduced sockeye survival. There is no evidence though for such an event in the freshwater environment in 1981 or 1982. The north temperate marine environment, however, was subjected to an anomalous warming trend in 1982 and 1983, commonly referred to a El Nino (Mysak 1986). There is, however, no evidence that El Nino may reduce survival of sockeye salmon. To the contrary, Mysak (1986) has suggested survival may actually increase as the result of greater zooplankton production associated with the warmer waters.

The selection of the model (Table 1) that provides the most reliable forecast of the total sockeye return in 1987 is difficult. Model II assumes the 1986 data point (Fig. 5) is essentially an outlier and therefore provides production system. Model III, which includes all data points from 1977-1986, assumes the converse. Model IV portrays the most conservative approach assuming that the system is limited to a maximum annual production of approximately 550000 adult sockeye salmon. Given the uncertainty in events that led to the low return in 1986 despite large brood year escapements and the large escapements to bhe brood years contributing to the 1987 return (1982, 1983) it is suggested that initially the 1987 Area 10 sockeye salmon fishery should be managed assuming a minimum total return of approximately 500000. However, fishery managers should also be prepared to deal with a total run that may reaach approximately 1000000 fish. Forecasts of total returns for the years 1988-1990 (Table 1) should be updated and re-evaluated prior to 1988 based on the actual and expected returns in 1987.

ACKNOWLEDGMENTS

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